SCHOOL OF CIVIL ENGINEERING

JOINT HIGHWAY RESEARCH PROJECT

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THIN, APPLIED SURFACING FOR IMPROVING SKID RESISTANCE OF CONCRETE PAVEMENTS

C. F. Scholer

PURDUE UNIVERSITY
INDIANA STATE HIGHWAY COMMISSION

Final Report

THIN, APPLIED SURFACING FOR IMPROVING
SKID RESISTANCE OF CONCRETE PAVEMENTS

TO: H. L. Michael, Director
Joint Highway Research Project

December 3, 1980

Project: C-36-53L

FROM: C. F. Scholer, Research Associate
Joint Highway Research Project

File: 9-6-12

The attached Final Report titled "Thin Applied Surfacing for Improving Skid Resistance on Concrete Pavements" is submitted for approval. The report has been prepared by Prof. C. F. Scholer and is largely based upon work previously reported by Mr. Jorge Gomez-Dominguez and Mr. Ryan Forrestel, Graduate Instructors in Research in the first and second interim reports on this project.

This report describes the study which has led to very thin portland cement mortar overlays being used to re-establish high skid resistance on worn low friction concrete pavements.

The Report is presented for review and acceptance as fulfillment of the objectives of the study. Upon such acceptance by the Advisory Board it will be forwarded to ISHC and FHWA for review and similar acceptance.

Respectfully submitted,

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Final Report

THIN, APPLIED SURFACING FOR IMPROVING SKID RESISTANCE OF CONCRETE PAVEMENTS

BY

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Conducted by

Joint Highway Research Project
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Purdue University

in cooperation with the

Indiana State Highway Commission

and the

U.S. Department of Transportation
Federal Highway Administration

The contents of this report reflect the views of the author who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

Purdue University
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16. Abstract

The use of select aggregate in a thin wearing surface of portland cement mortar to prolong or restore a concrete pavement's ability to develop high friction was accomplished in this project.

Two fine aggregates, blast furnace slag and lightweight expanded shale were found to exhibit skid resistances greater than the other aggregates evaluated. The British Polishing Wheel was used in the Laboratory evaluation of aggregate to simulate wear.

The need for a method of restoring friction to a worn, but otherwise sound, concrete pavement led to a field evaluation of several different techniques for placing a very thin overlay. The successful method was a broomed, very thin layer of mortar, 3 mm thick.

This technique combined with portland cement mortars containing either latex or acrylic admixtures and either of the select aggregate was found to adhere well and provide very high skid numbers when tested by a skid trailer over a period of 2-1/2 years. The tests were on a lightly travelled highway.

The shallow depth of the overlay was essential for a good adhesion to the casting pavement and also resulted in economy because of the small volume of material required. The test strips were successfully placed on existing pavement without other preparation of the pavement surface. Oil or paint would require surface cleaning.

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INTRODUCTION

Highway safety is dependent upon the ability of travelling vehicles to control their direction and rate of movement by developing good friction between the vehicle tires and the pavement surface. Situations where friction does not develop frequently result in serious accidents. Many reasons exist for the lack of sufficient friction and this research deals with only one of the causes i.e. the influence of a portland cement concrete pavement surface upon friction.

Many concrete pavements have, and will be placed, with good skid resistant resulting from the high friction which exists on the newly finished pavement which nearly always has a good macro texture for developing this friction. With heavy traffic this good texture will experience wear and lose part of its ability to develop high friction. In some circumstances this can become a condition in which traffic safety is greatly influenced.

OBJECTIVE

The goal of this research was to develop a means of restoring, and/or prolonging a concrete pavement's ability to develop high friction and to identify materials which will best maintain high friction even when traffic has worn, or polished, the pavement surface.

EXECUTIVE SUMMARY

The first portion of this investigation* identified the materials which would perform best in resisting wear and maintain high friction. Materials considered were available in, or near, to Indiana. Very high cost materials, such as silicon carbide, were not considered in the investigation. The results of this portion of the investigation are applicable to both new construction and to friction restoration projects. A wearing course of these materials could be placed on new concrete pavement to aid in its better maintaining high friction values under heavy traffic.

Friction restoration is needed on many pavements which are structurally sound but whose surfaces are worn and polished to the extent that adequate friction, for vehicle safety, may not exist. Great emphasis was given to this phase of the research.

Very little, if any, attention had been directed toward the use of very thin portland cement mortar overlays on highway pavements. With the idea of investigating this possibility, the laboratory study of material and their polishing resistance included all materials believed applicable to such overlay applications on Indiana highways, streets amd bridges. The materials included portland cement, latex and acrylic admixture, slag, lightweight aggregate and natural aggregates.

The two materials identified in the laboratory investigation as giving superior friction values, even after extensive wear as measured by the

*Gomez-Dominguez, Jorge, First Interim Report, "Mortar Mixtures for Thin Skid Resistant Concrete Surfaces" JHRP-78-8.

British Polishing Wheel method, were blast furnace slag from northern Indiana and expanded shale structural lightweight concrete aggregate from the center portion of the state. Both the latex and acrylic admixtures gave improved adhesive qualities.

Development of the very thin overlay was done solely with these materials because of their proven performance under the severe abrasive polishing of the laboratory tests.

The second part of this research dealt with the evaluation of techniques for applying very thin concrete overlays to old, worn, concrete pavement. In the context of this research, a very thin overlay was defined as being approximately 3/8 inch in depth or less. Particular emphasis was given to the feasibility of field application techniques. It was anticipated that with the procedures for overlay application, and given the proper equipment, one or more of the techniques could be used economically and efficiently to improve skid resistance in small, local areas or large, sectional areas. Overlay adherance to old concrete, achievement of rapid set in the overlay and achievement of initially high skid numbers, also were considered.

Numerous trial applications of various techniques were evaluated on small text areas with the result that further field evaluation was warranted on an actual pavement. This field evaluation was conducted on a straight section of a badly cracked but mostly bare concrete rural highway. The details of this work were reported by Forrestal*.

These test sections of very thin overlays have been monitored for two and one-half years for both their ability to adhere and for their skid numbers by ASTM E-274.

*Forrestel, Ryan R., Second Interim Report, "Application and Field Evaluation of Very Thin Skid Resistant Pavement Surfaces" JHRP-78-12.

The technique called brooming has been the most successful for it has adhered well to the underlaying pavement even though no special surface preparation was given to the old pavement. In addition, this technique produced high friction pavements which have retained their high skid numbers through two winters and the low volume of mixed traffic.

The traffic was low in volume and in speed. No stops, or curves, exist in the test section. The excellent results of the broomed section warranted further evaluation under conditions of heavy traffic.

Recommendations for further evaluation of the technique were made for the following reasons.

1. High skid numbers were obtained and maintained with this technique.

2. Excellent adhesion of the very thin broomed overlay to the existing pavement surface have been mentioned for more than two full years.

3. The very thin broomed overlay, 1/8 inch nominal thickness, if it does lose adhesion, will break up and not be of danger to traffic.

4. The very thin overlay is economical in that a modest volume will cover a large area hence the cost of the expensive admixtures are not so great a factor in the total cost.

5. The time during which traffic was not allowed on the newly placed pavement was four to twelve hours. This difference depends upon temperature and whether traffic is frequently accelerating or decelerating in the overlay section.

The favorable results of this research resulted in the Indiana State Highway Commission letting an experimental contract for the placement of this material on Ind SR 37. Placement of the very thin overlay was made in late September 1980. The initial results of this installation, which has heavy traffic and a stop light, are promising.

IDENTIFICATION OF MATERIALS HAVING THE BEST FRICTION AFTER EXTENSIVE WEAR

A large number of materials can produce a good macro texture with resulting high friction. Only some of these materials maintain desirable friction after they have been subjected to extensive wear. Two materials, blast furnace slag and expanded shale, available from commerical sources within Indiana, were identified as having this desired friction. This laboratory investigation* is summarized in the following pages.

Mixes having a variety of materials were evaluated for friction after each specimen had been subjected to eight hours of wear on a British Polishing machine. This apparatus holds fourteen specimens on the outside of the large wheel, pictured in Figure 1, which rotates in contact with a standard rubber "tire" and with silicon carbide and water fed onto the surface in front of the tire contact area.

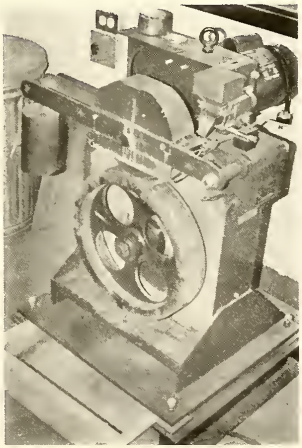


Figure 1. British Polishing Machine

*A more complete description is available in the First Interim Report, Gomez-Dominguez, Jorge, "Mortar Mixtures for Thin Skid Resistant Concrete Surfaces" JHRP-78-8.

The specimens, such as shown in Figure 2, are thus tested on a portable skid tester which is pictured in Figure 3. The results give meaningful comparisons with other tests on this machine but cannot universally be well correlated with skid trailer readings.

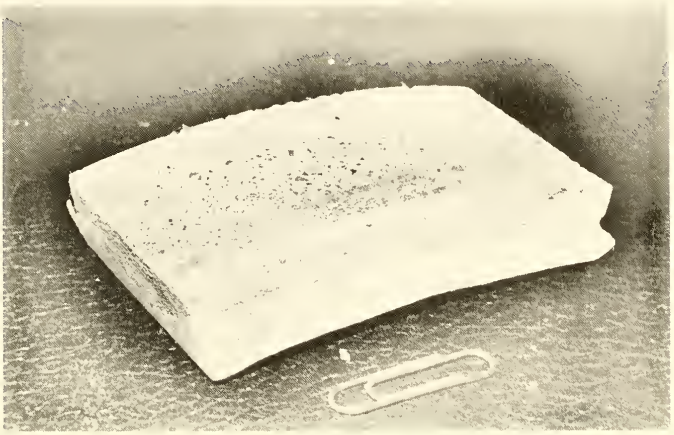


Figure 2. Test Specimen After Eight Hours Wear on British Polishing Machine.

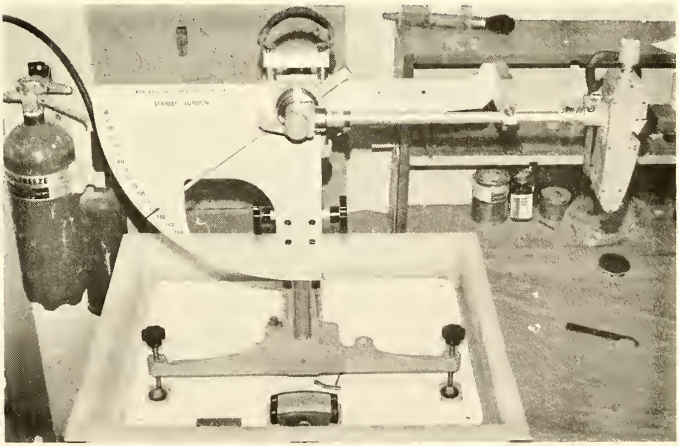


Figure 3. Portable Skid Tester (British Pendulum) Used to Measure Friction in the Laboratory.

The results of these skid tests are given in Table 1 and 2. The results of the initial evaluation of different admixtures and aggregate were difficult to interpret thru analysis of variance techniques. No single mix was significantly better; however, some could be eliminated. Most notably the natural sand gave lower friction values. Also, water cement ratio had little significance on skid number.

Further tests concentrate on slag and lightweight aggregate and what appeared to be their optimum proportions. Figure 4 presents the results of these tests. Lightweight aggregate mortar after being subjected to the British Polishing Wheel consistently gave somewhat higher values for skid number than did slag. The ratio of aggregate-cement (by weight) did not have meaningful influence on skid numbers.

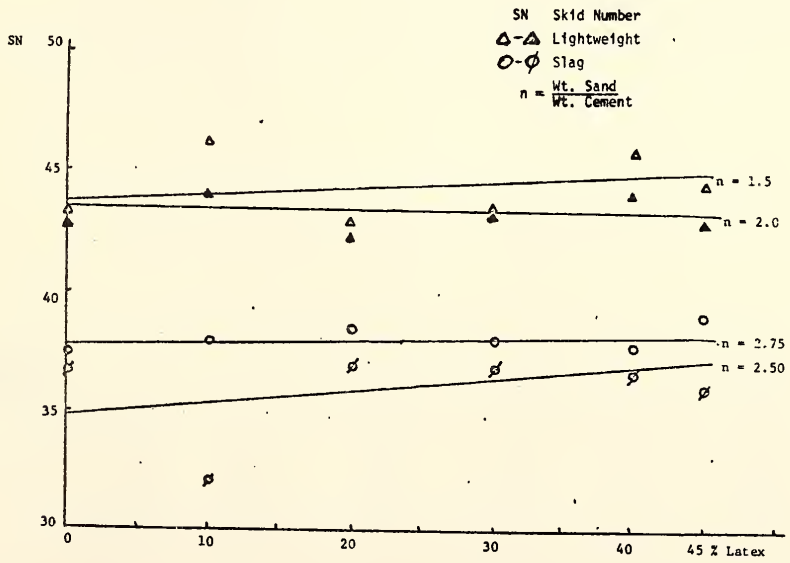


Figure 4. Effects of Latex on the Skid Resistance

Table 1. Final Skid Numbers for Slag

Wt. Sand / Wt. Cement	Percent Latex* 0%	10%	20%	30%	40%	45%
2.50	34	28	36	37	39	37
	37	37	35	37	39	39
	39	32	40	37	39	32
	37	31	37	36	34	36
	(36.75)	(32.00)	(37.00)	(36.75)	(37.75)	(36.00)
2.75	38	41	37	40	36	39
	36	38	38	37	39	41
	36	36	38	38	37	39
	40	37	41	37	34	37
	(37.50)	(38.00)	(38.50)	(38.00)	(36.50)	(39.00)

* By weight of cement

Table 2. Final Skid Numbers for Lightweight

Wt. Sand / Wt. Cement	Percent Latex* 0%	10%	20%	30%	40%	45%
1.5	42	45	43	43	46	44
	46	49	44	43	45	47
	42	47	42	43	46	43
	41	44	42	44	46	44
	(42.75)	(46.25)	(42.75)	(43.25)	(45.75)	(44.50)
2.0	43	44	43	44	44	43
	43	44	42	43	44	41
	43	44	40	42	44	44
	44	44	44	45	44	43
	(43.25)	(44.00	(42.25)	(43.50)	(44.00)	(42.75)

* By weight of cement

Compressive strengths of two inch cubes are shown in Tables 3 and 4. These are with a water-cement ratio of 0.45.

Table 3. Strength of Cubes for Lightweight (psi)

Wt. Sand / Wt. Cement	Percent Latex* 0%	10%	20%	30%	40%	45%
1.5	4570	5010	5480	3670	6130	6470
2.0	4060	4650	4700	4750	5440	5680

Table 4. Strength of Cubes for Slag (psi)

Wt. Sand / Wt. Cement	Percent Latex* 0%	10%	20%	30%	40%	45%
2.50	6290	7440	7710	9140	9290	10190
2.75	5880	6130	7050	7280	7570	8110

* By weight of cement

The gain in strength by the use of the latex admixture should be noted. This aids in understanding the good adhesion found in the field performance of sililiar mixes.

These results show no detrimental effects on skid resistance when latex is used over the range of 0. to 45% by weight of cement,

Findings which gave the primary guidance to the field evaluation were:

a) The principle factors that influence friction characteristics in a mortar is the aggregate hence slag and structural lightweight expanded shale were recommended for field evaluation.

b) Lower water-cement ratios and higher sand-cement ratios tend to give slightly better friction but not of great statistical significance. This indicates that variation in these mix parameters, in the field, would not seriously effect the skid numbers.

c) Good workability was achieved by mixes made up of sand size slag with sand to cement ratios of 2.5 and 2.75. Also, for lightweight aggregate with sand-cement ratios of 1.5 to 2.0. All of these were at a water-cement ratio of 0.45.

The results of the laboratory investigation were used in developing the field mixtures and procedure.

FIELD EVALUATION*

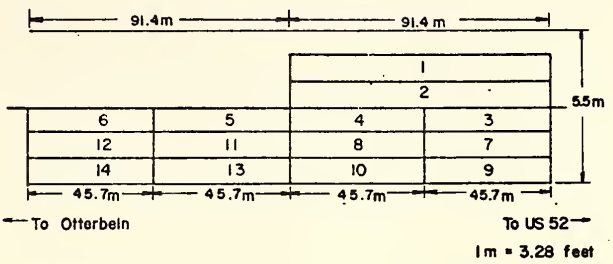
The primary field evaluation was done on an old highway pavement, 18 feet wide with 60 feet between joints. It had many cracks with some faulting and bituminous patching. Although badly pitted and cracked the concrete surface was relatively free of oil and dirt. No surface cleaning was done. Neither was bituminous material removed (adhesion was poor on bituminous areas).

An initial placement of overlay was made in the fall of 1977, it provided experience in technique which was valuable in designing and

* A more complete description is available in the Second Interim Report, Forrestel, Ryan R., "Application and Field Evaluation of Very Thin Skid Resistant Pavement Surfaces" JHRP-78-12.

planning the test strip placed in May of 1978. The test strips shown in Figure 5 were large enough to permit the Indiana State Highway Commission to conduct skid trailer tests to measure skid numbers.

(a)



(b)

Strip No.	Part No.*	Application Technique	Overlay Depth Meters	Mix No.
1	One	Screeding	0.009	1
2	One	Brooming	0.009	2
3	Two	Screeding	0.009	3
4	Two	Screeding	0.009	4
5	Two	Screeding	0.009	5
6	Two	Screeding	0.009	6
7	Two	Brooming	0.003	7
8	Two	Brooming	0.003	8
9	Two	Brooming	0.003	9
10	Two	Brooming	0.003	10
11	Two	Brooming	0.003	11
12	Two	Brooming	0.003	12
13	Two	Brooming	0.003	13
14	Two	Brooming	0.003	14

*Part No. One - placed in October 1977
Part No. Two - placed in May 1978

0.003 meters = 1/8 inch

Figure 5. Layout of Overlays

The plan was to place the strips by three techniques, screeding with temporary forms on the side of the strip to provide confinement and depth

control, shotcreting to spray a thin layer directly onto the concrete and to broom, or brush, a thin layer of mortar over the surface.

Screeding gave good control of depth; but required a coarse broom to produce a good macro texture. It was later found that these sections did not adhere well. For that reason they are not recommended.

The shotcrete section were unavoidably deleted when essential control valves were stolen and time was not available to obtain replacements before the construction crew finished the working period. Fortunately, the success of the brooming methods aleviated the need for evaluating shotcrete since brooming appears to be the more economical of the two methods.

The brooming methods were initially used for a 3/8 inch thickness but it was found to produce a very irregular thickness. However, it was noted that a thin layer could be spread, essentially one aggregate particle diameter in depth, with an excellent texture and good control. This method was used for strips #7 thru #14. Good adhesion and skid resistance were found in all of these test strips.

The shallow thickness, 1/8 inch for these overlays, in conjunction with the effect of vigorous brooming resulted in good adhesion. Cracks occurred through this very thin overlay with ease, but the bond between the overlay and the underlaying pavement was not disturbed. The bond was frequently lost in the thicker sections hence it is believed that a very thin, 1/8 inch, overlay (not measuring aggregates protruding from the surface) is essential to obtain good adhesion.

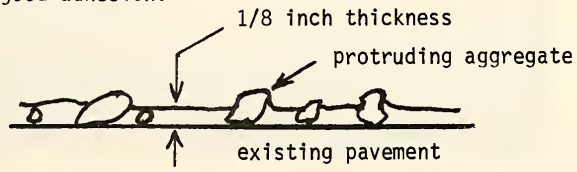


Figure 6. Conceptual Drawing of a Very Thin Overlay

Figure 7. Broom Application of a Test Strip

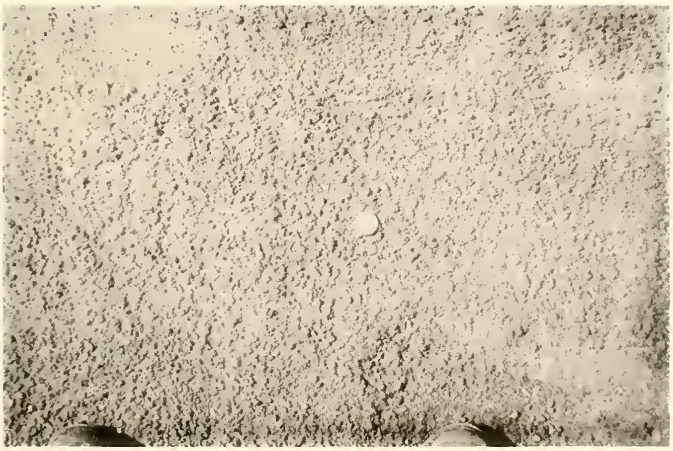


Figure 8. Surface Texture of a Broomed Very Thin Overlay.

The mixes are given in Table 5. Mixes varied in ease of application but results were not greatly different. Mix #10 has a smaller volume of aggregate and it appears to have a lower skid number but this is to be expected.

Table 5. Strip Mix Designs

Strip	Aggregate	Absorption (%)	m[a]	Desired w/c	Cement (Kg)	Aggregate[b] (Kg)	Latex[c] (%)	Latex (Kg)	Antifoam[d] B
1	sand	2.5	2.75	.45	26.65	79.43	None	None	None
2	sand	2.5	2.5	.45	26.65	72.63	None	None	None
3	slag	4	2.5	.45	26.65	69.29	40	10.66	.43
4	slag	4	2.75	.45	26.65	76.20	40	10.66	.43
5	lightweight	15	1.5	.45	26.65	45.97	45	12.00	.43
6	lightweight	15	2.0	.45	26.65	61.29	45	12.00	.48
7	lightweight	15	1.0	.45	26.65	30.65	45	12.00	.43
8	lightweight	15	1.5	.45	26.65	43.97	45	12.00	.48
9	slag	4	2.25	.45	26.65	62.36	40	10.66	.43
10	slag	4	2.0	.45	26.65	55.43	None	None	None
11	slag	4	2.5	.45	26.65	69.29	40	10.66	.43
12	slag	4	2.0	.45	26.65	55.43	45	12.00	.48
13	slag	4	2.5	.45	26.65	69.29	40	10.66	.43
14	lightweight	15	1.5	.45	26.65	43.97	None	None	None

a. m = sand-cement ratio, by weight
b. Aggregate weight = (weight of cement x m) + (weight of cement x m x absorption)
c. Liquid Latex, by weight of cement
d. Antifoam B is 1.82% of latex, by weight

Table (Continued)

Strip	Rhoplex[e] (%)	Rhopflex (Kg)	Dow[f] Antifoam B	$CaCl_2$ (Kg)	Aggregate Moisture Content	Act. Water Added (Kg)	Total Water[g] Per Batch (Kg)	Actual w/c	Batch Volume (cu.m.)
1	None	None	None	None	8.3%	-	-	-	-
2	None	None	None	None	9.0%	-	-	-	-
3	None	None	None	None	7.0%	1.6	6.92	.44	0.051
4	None	None	None	0.80	8.1%	1.1	6.46	.47	0.055
5	None	None	None	0.80	20%	0.0	6.00	.57	0.055
6	None	None	None	0.80	12.9%	2.50	8.49	.52	0.064
7	None	None	None	None	6.0%	3.6	9.63	.43	0.050
8	None	None	None	None	5.8%	4.1	10.08	.47	0.051
9	None	None	None	0.80	7.0%	2.3	7.60	.45	0.049
10	32	8.50	.43	None	6.0%	3.6	8.14	.43	0.045
11	None	None	None	None	5.2%	4.5	9.87	.51	0.053
12	None	None	None	None	5.2%	2.3	3.26	.42	0.046
13	None	None	None	None	5.2%	4.5	9.87	.51	0.053
14	32	8.50	.43	0.80	9.5%	3.6	8.14	.46	0.049

e. Liquid Rhoplex, by weight of cement
f. Antifoam B is 2.29% of Rhoplex MC-76, by weight
g. The total amount of water added = (water from latex/acrylic) + (extra water)

In general, a successful mix must have sufficient aggregate to result in a coarse textured surface with the part having a water-cement ratio close to 0.45. Latex (Saran type) admixture was halpful and resulted in good adhesion with the brooming method. The two sections placed with acrylic admixtures also performed well.

Absolutely essential to success with the brooming method is to have a consistency which can be spread by the broom. The amount of water to accomplish this varied depending on whether the old pavement was wet or dry. This will no doubt need to be a variable to be adjust in the field. Both wet and dry pavement surfaces were successful in the field tests.

SKID NUMBERS AND PERFORMANCE OVER THIRTY MONTHS

The results of the skid number determinations by the Indiana State Highway Commission have been very good. High values have continued throughout the life of the test strips. Due to the rough condition of the old concrete pavement it has not been feasible to test all strips. (The roughness damaged the skid trailer). That is the reason that values are missing in strips #7 thru #14. Strips #1 thru #6 have generally delaminated hence were not measured. Typical skid numbers obtained on the test strips are summarized in Figure 9.

The complete results are given in Table 6.

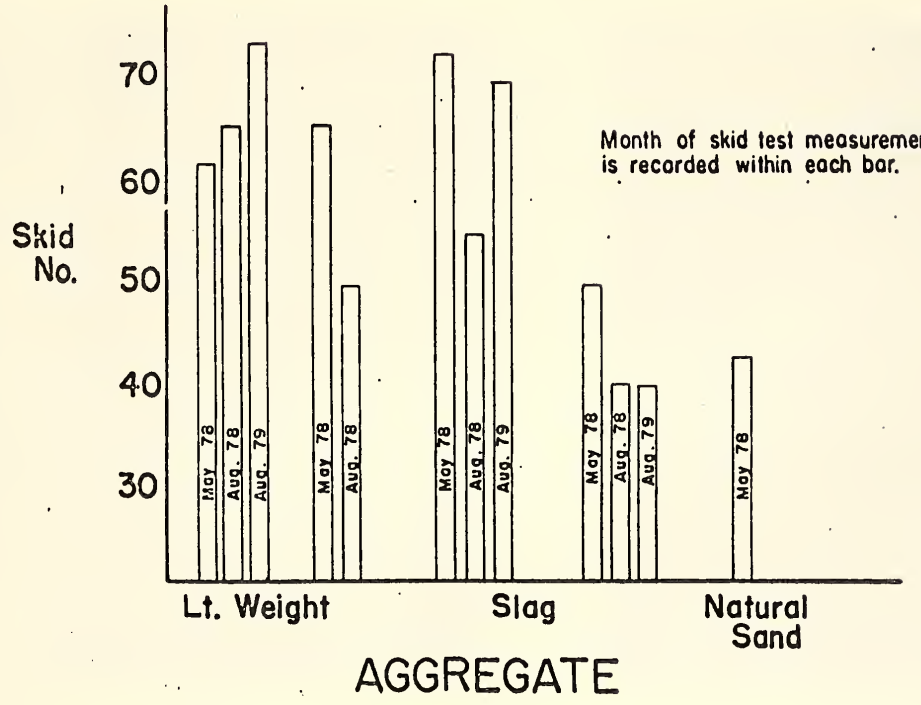
Table 6. Skid Numbers, from Skid Trailer Measurements at 40 mph.

Overlay Number	Skid Number			Standard Deviation			Overlay Technique	Aggregate
1*	40.6			-			screed	natural sand
2*	43.2			2.66			broom	natural sand
3	38.2	34.2		2.57	2.27		screed	slag
4	34.2	32.9		3.78	0.83		screed	slag
5	39.4	39.2		3.46	1.10		screed	lightweight
6	40.8	44.4		-	1.50		screed	lightweight
7	72.8	66.6		2.06	6.65		broom	lightweight
8	61.8	65.0	73.4	1.32	-	2.67	broom	lightweight
9	50.9	42.7	50.0	2.10	1.44	2.95	broom	slag
10	49.1	39.8	39.8	1.66	-	3.14	broom	slag
11	72.6	54.8	69.3	2.27	4.17	3.11	broom	slag
12	59.0	55.2		1.71			broom	slag
13	62.8	49.4	62.4	3.40	7.74	2.81	broom	slag
14	65.2	49.5		1.96	-	-	broom	lightweight
Date of Skid Test	5/31/78	8/31/78	8/11/79	5/31/78	8/31/78	8/11/79		

* Part One data recorded one week upon completion of overlay number 2.

** Standard deviation based upon three measurements

FIGURE 9 SKID TRAILER MEASUREMENTS



The better test strips have performed very well over two and one-half years. Figure 10 and 11 show the current condition of the test strips.

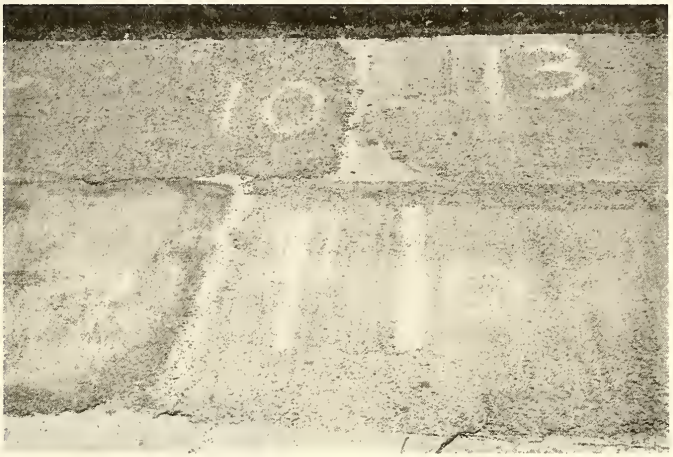


Figure 10. Appearance of Test Strips at 28 months, Strip #8 Has Lightweight Sand and Strips 10, 11 and 13 were constructed with Slag Sand.

Figure 11. Appearance of Test Strips at 28 months, Strips 11 and 12 were constructed with Slag Sand and Strip 14 with Lightweight Sand. The Severe Cracking and Delamination Showing in Strip 12 is at a Joint with Bituminous Patching Material.

IMPLEMENTATION

The favorable performance of the field test strips resulted in the Indiana State Highway Commission placing a short section of very thin overlay by contract in September 1980. This 1,050 foot section was at an approach to a stoplight on a heavily travelled, four land highway. After two months it is performing well with skid numbers comparable to those obtained on the good test strips reported in this investigation. An encouraging result is that the very thin overlay withstood the action of skidding truck tires at ages as young as fifteen hours without damage.

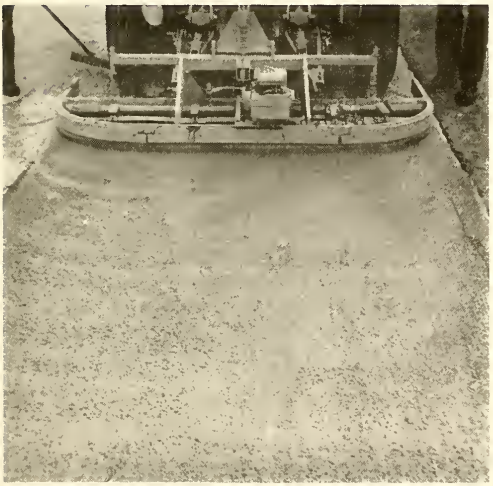


Figure 12. Application of Very Thin Overlay on SR 37 September 1980

Figure 13. Skid Marks on Completed Overlay, SR 37 October 1980

This contract included three methods of surface preparation, sand blasting, "rotormilling" and "blastrac", the latter a steel shot abrasion with vacuum collection of dust along with the reuse of the steel shot. All methods were capable of satisfactorily preparing the surface. On this job the sand blasting was very slow, the "roto milled" surfaces required

high pressure air brushing to remove a packed dust layer. The "blastrac" was the most impressive since it was faster than the other methods and did a good job and the depth of surface removed was easily controlled. This project used blastfurnace slay for aggregate. Subsequent to this contract a small additional portion of this surface was applied to the highway with no preparation being given to the pavement. This section was placed with lightweight, "Haydite" aggregate. It should be noted that this was not on a section adjacent to the stop light hence the pavement did not have as much oil and rubber on the surface.

The placement was made by using an old slurry spreader which had a set of brooms which were effective in brushing in the material. A flexible "skirt" provided the final spreading of the mixture. The resulting texture was generally coarse with the individual particles protruding from the surface to give the high skid resistance.

Future implementation will no doubt depend upon the performance of the current experimental project. Experience from this project will give guidance to future work especially in the importance of surface preparation methods, placement procedure and control of free water on the pavement surface.

CONCLUSION

Quality, very thin overlays on pavement surfaces require select aggregates which create a good macro texture for high friction and will also maintain reasonable friction after wear and polishing from traffic.

The use of latex, or acrylic admixtures, promotes high strength and good adhesion of a very thin overlay to the existing pavement. Water-cement ratio should be controlled with 0.45 being a feasible value. Excess water on pavement surfaces will alter this hence should not be allowed.

Although not a conclusion based upon the experimental investigation, a finding from field observations, was that adhesion was not developed on bituminous material, paint or adhered fine material. The latter is the result of observations of the implementation project on State Rd. 37 where small areas with poor adhesion, were associated with fines adhered to the underlying, roto-milled concrete.

The applied material should be worked into the existing pavement by vigorous brooming. The resulting pavement thickness should be 1/8 inch thick except for protruding aggregate particles.

This method continues to be an attractive approach to increasing the pavement friction of surface which no longer have adequate skid resistance. At this time continued implementation of these findings are recommended.

ACKNOWLEDGEMENTS

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